Are Diamonds LRT's Best Friend? At-Grade LRT Crossing at a Diamond Interchange

By Nate Larson and Abhishek Dayal

ABSTRACT

The Phoenix metro area's high-capacity transit provider, Valley Metro Rail (METRO), is in the midst of a major expansion program—building on the success of its initial Light Rail Transit (LRT) line, which opened in 2008. New lines and extensions are being planned, designed and constructed to serve existing and future activity centers. One of these, the Phoenix West Extension (PWE), would extend LRT from the existing starter line westward to the edge of the City of Phoenix, primarily along I-10, the major east-west freeway in the metro area. As with all major infrastructure projects, balancing costs with benefits was paramount. This goal led METRO to identify the I-10 right of way as the best place for LRT in the western part of the PWE corridor, and to consider north side-running tracks at-grade. The traffic impacts of an at-grade LRT crossing adjacent to an interchange were evaluated at a planning level using a traditional traffic operations analysis tool (Synchro) and later at a conceptual engineering level using microsimulation (VISSIM). These two analysis techniques produced different results, although both indicated that the proposed operation, within selected constraints, would not cause substantial delays to either LRT or traffic. This paper discusses potential reasons for the two analysis methods producing such different results and the conditions under which an at-grade crossing solution was considered and analyzed, with attention to both kinds of coordination—between jurisdictions and between signal hardware—that made it possible to consider an at-grade solution in a high-traffic environment.

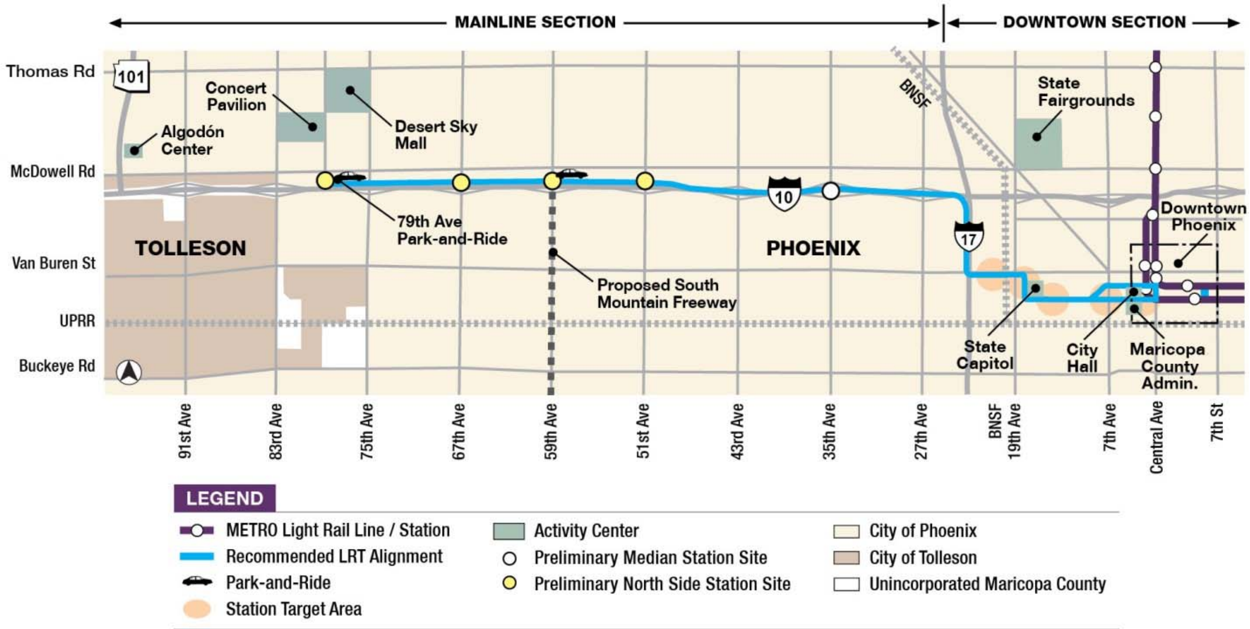
1.0 OVERVIEW

The traffic study summarized in this paper was initiated to examine the traffic impacts of potential future Valley Metro Rail Inc. (METRO), Light Rail Transit (LRT) operations in the Phoenix West Corridor. This study specifically examined the impact to street traffic on 51st Avenue if the LRT guideway were to cross the major north-south arterial at-grade just north of I-10. The conduct of this study was guided by a technical review committee comprised of staff members from METRO, Maricopa Association of Governments (MAG), Arizona Department of Transportation (ADOT), and the City of Phoenix (Phoenix). This committee also formulated the recommendations identified as part of this study.

1.1 The Phoenix West Extension Project

The passage of Proposition 400 by Maricopa County voters in November of 2004 initiated a substantial increase in public funding for public transit. Proposition 400 also represented the public's desire to provide a transportation system that could accommodate regional growth. A portion of the funds from the Proposition 400 half-cent transportation sales tax were allocated toward the 57.7-mile High Capacity Transit (HCT)/LRT system identified in the MAG Regional Transportation Plan (RTP). The 20-mile Central Phoenix/East Valley (CP/EV) LRT Starter Line that serves the cities of Phoenix, Tempe, and west Mesa opened for passenger service in December of 2008. The MAG RTP identified an 11-mile extension along west I-10, from the CP/EV LRT Starter Line in downtown Phoenix to the vicinity of 79th Avenue, as one of six additional HCT/LRT corridors within Maricopa County (MAG 2003). This segment of I-10, defined as the Phoenix West Corridor, is scheduled to be in operation by 2023, with the remaining system to be operational by 2032.

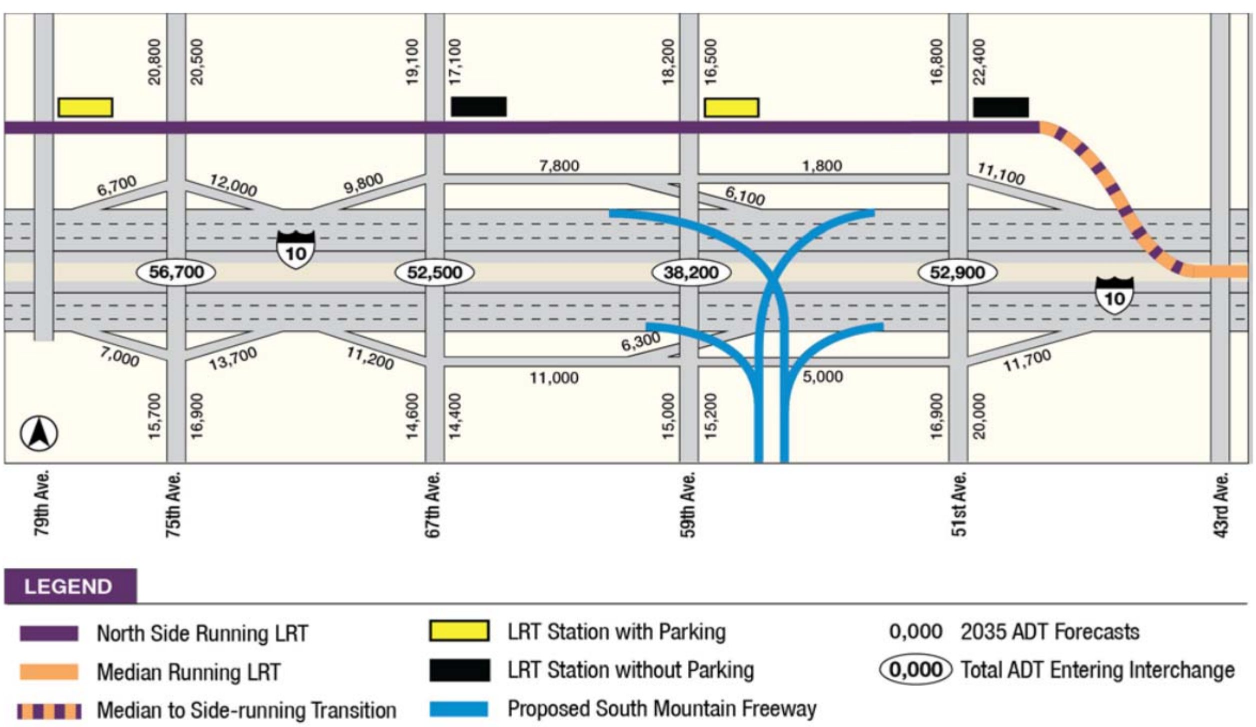
METRO identified an alignment alternative in coordination with ADOT that would place the potential new LRT tracks along the north side of I-10 from approximately 47th Avenue to the alternative's terminus at the Desert Sky Mall near 79th Avenue. This alignment would be located for the most part within the existing ADOT right-of-way (ROW) and is identified as "North Side Running." The study area is shown in **Figure 1**.



BNSF = Burlington Northern Santa Fe; UPRR = Union Pacific Railroad
Source: METRO, 2011.

Figure 1. Phoenix West AA/EIS Study Area

In this north-side configuration, the guideway would cross four major north-south arterials: 51st Avenue, 59th Avenue, 67th Avenue, and 75th Avenue. The proposed station locations, park-and-ride facilities, MAG 2035 forecast traffic volumes, and ramp configurations along I-10 associated with the planned SR 202 Freeway system interchange are illustrated in **Figure 2**.



Note: I-10 lanes shown are illustrative only, and do not represent existing or projected number of lanes
Source: METRO, 2012.

Figure 2. LRT Alignment, Interchange Configurations, and 2035 Traffic Volumes

As shown schematically in Figure 2, the SR 202 South Mountain Freeway project would include a reconfiguration of the I-10 on- and off-ramps at 51st, 59th, and 67th Avenues. A new collector-distributor (C-D) roadway would be added in each direction between 51st and 67th Avenues that would separate I-10 access traffic from the SR 202 South Mountain Freeway interchange traffic. This change is significant because with the C-D road system, ramp traffic associated with multiple interchanges must go through the signals either end of the C-D road, while without it each interchange only handles local traffic.

Even though the LRT guideway would cross as many as four major interchange areas at grade, the traffic study was conducted for a single interchange because the four interchanges share general geometric and traffic operating characteristics. Phoenix, ADOT, and METRO agreed to model at-grade crossing impacts for a single interchange location initially, and that the traffic study could be expanded to include the other three interchanges at a later time. These crossings could be either at-grade or grade- separated. The crossing at 51st Avenue was chosen as the basis of this analysis for the following reasons:

- Highest projected total entering 2035 traffic volume for the ramp intersections (combined)
- Highest average vehicle delay for the combined ramp junction intersections
- High level of truck activity due to industrial land uses and truck service facility
- Continuity of 51st Avenue to the north and south across the region

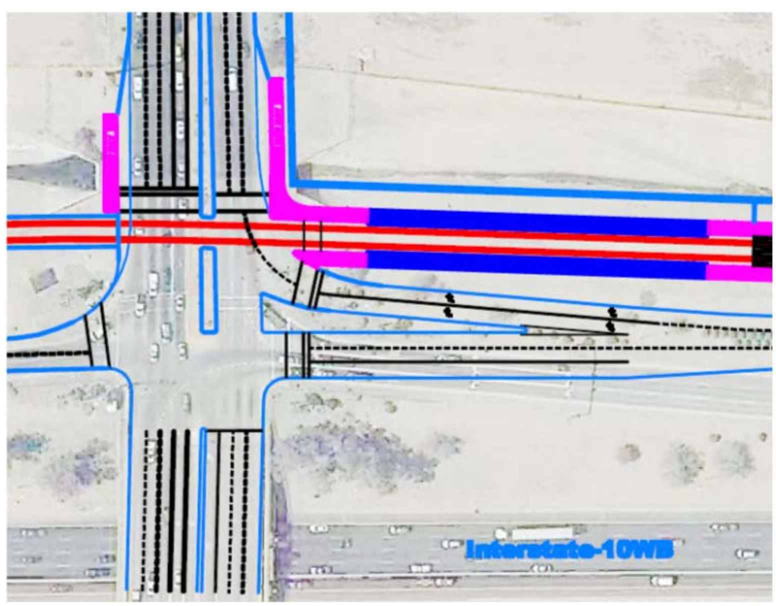
This study examined the part of 51st Avenue from Roosevelt Street on the south to McDowell Road on the north (a distance of about ½ mile), and focuses on the two intersections with the on- and off-ramps to I-10 eastbound and westbound.

1.2 Scenarios Tested

In most cases, LRT running along the edge of a freeway would be grade-separated at all major arterial crossings, including those with freeway interchange ramps. The proposed action this study was designed to test is an at-grade crossing.

The **Grade-Separated Scenario** is the basis for measuring the impacts of the proposed improvements described in the "At-Grade" scenario. In terms of traffic, the grade-separated scenario is basically the same as if no LRT tracks were present at all.

The **At-Grade Scenario** features an inter-section-style LRT at-grade crossing of 51st Avenue as part of the intersection of the I-10 Westbound ramps. A basic drawing of the proposed LRT guideway near 51st is shown in **Figure 3**. The stop line for south-bound vehicles would be moved to the north to accommodate the trackway. This analysis assumed that the crossing would not be gated but all audible and visual warning devices would be employed. The intersection would include pedestrian cros-sings of the east, west, and north legs. The pedestrian crossing of the north leg would be made in two stages, with a safe waiting area and additional pedestrian detection provided in the median of 51st Avenue.



Source: METRO, 2011.

Figure 3. At-Grade Scenario

2.0 METHODOLOGY AND ASSUMPTIONS

This section describes the methodology and assumptions used in the study. This traffic study brought together traffic-related data from several sources to help determine the feasibility of an at-grade LRT crossing of 51st Avenue at I-10, including MAG, the City of Phoenix, METRO, and ADOT.

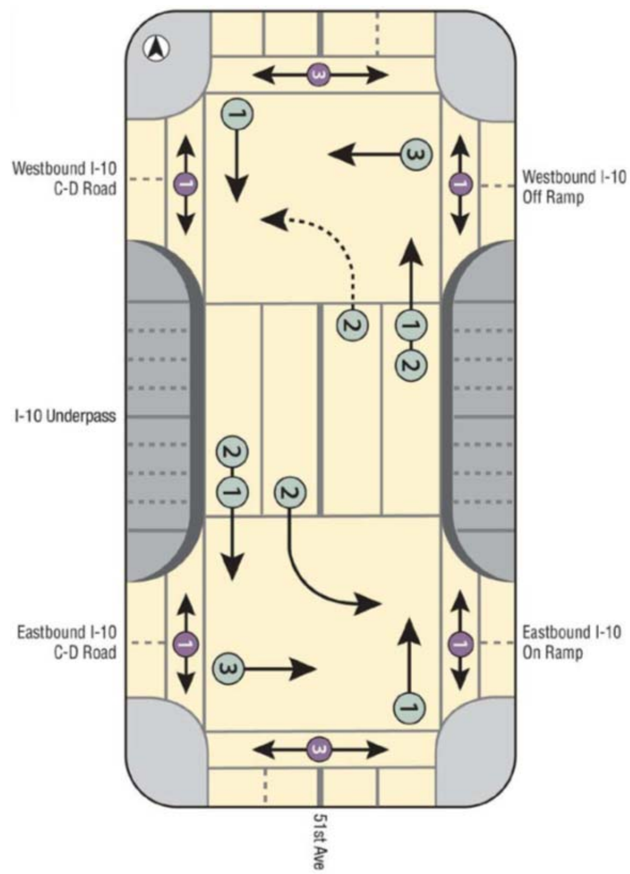
2.1 Base Model

At METRO's request, ADOT provided the Synchro (2030 volumes) and VISSIM (2035 volumes) models developed for the SR 202 South Mountain Freeway project by its corridor management consultant. Use of these models avoided duplicating effort on two fronts: (1) building the model networks including key interchange features and signal operations, and (2) calibrating the models with respect to key driver behavior parameters.

2.2 Signal Timings

Grade-Separated Scenario. Intersection signal timing data were provided by two sources. ADOT provided existing signal timings for the two I-10 ramp-junction intersections. The City of Phoenix provided timings for the signals at the next intersections north and south of I-10 along 51st Avenue (McDowell and Roosevelt). The ramp junction intersection signals are controlled by a single signal controller, and timings are actuated, with a cycle length of 90 seconds.

Figure 4 shows the traffic signal phasing used at the 51st Avenue/I-10 interchange. North is to the top of the figure, and the center of the figure represents the 51st Avenue bridge over I-10. Northbound traffic turning left on to I-10 has both a protected left (green arrow) and a permissive left (green ball, yields to southbound traffic). This type of left turn phasing helps provide additional capacity and flexibility, especially during off-peak periods, which is helpful because the northbound left-turn movement can be made from only one lane. The southbound left turn has two lanes and is protected-only at all times.

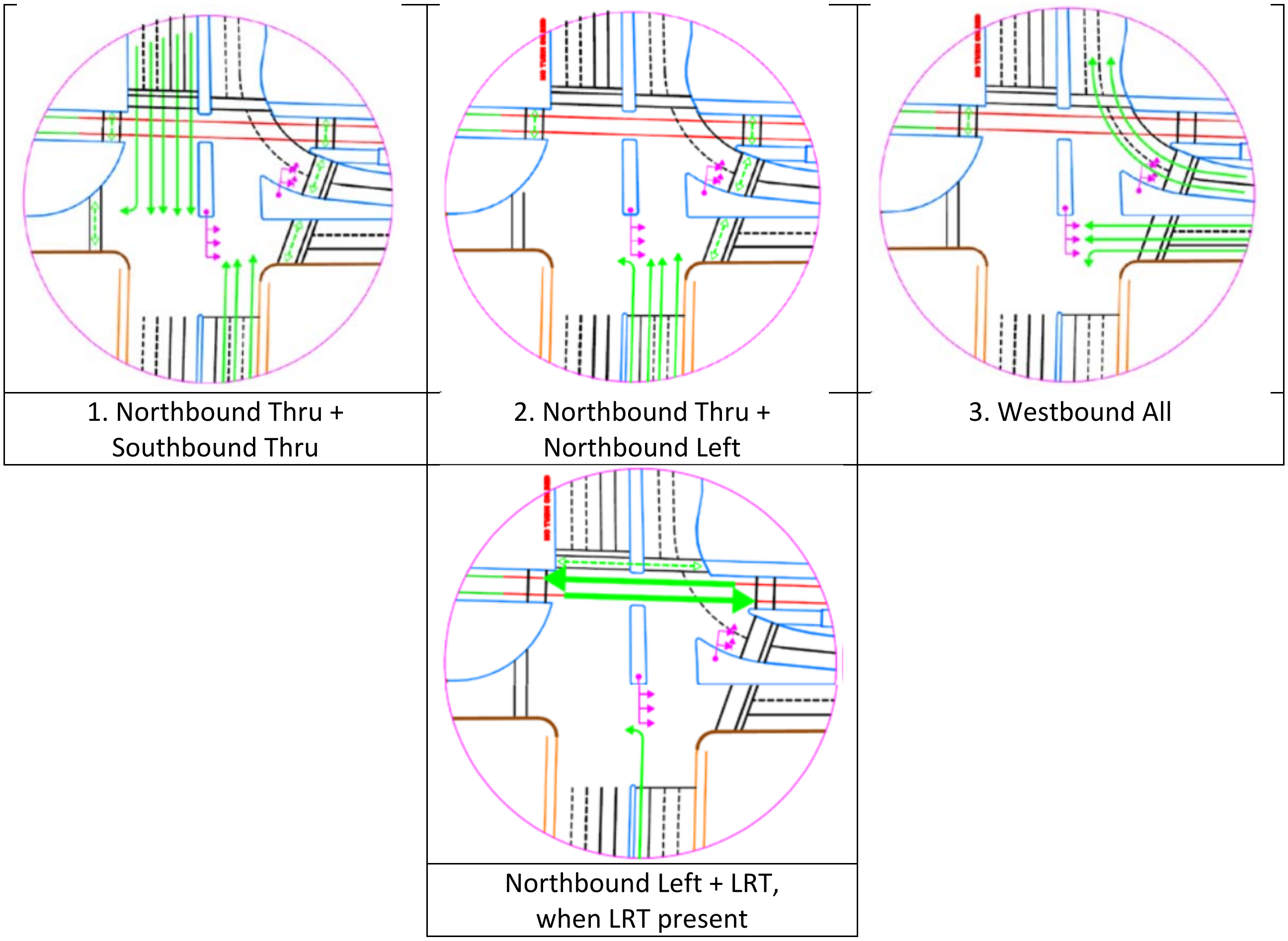


Source: METRO, 2011.

Figure 4. Traffic Signal Phasing at the I-10/51st Avenue Interchange

At-Grade Scenario. Under the conditions examined, LRT would only be allowed to cross the intersection during Phase 2. When a train passes through the intersection during Phase 2, the northbound through traffic on 51st Avenue would have to stop, but the northbound left-turning traffic would not need to stop because it does not cross the LRT guideway.

The form of LRT priority examined in this initial study is the replacement of a normal signal phase with one that allows LRT to cross. Rather than the traditional railroad-style 'clearance – passage – recovery' operation, the signal controller would simply replace the conflicting movement with the LRT movement during the appropriate phase. In this case, it would replace "NB Through" with LRT. A phasing diagram for the 51st Avenue/Westbound I-10 Ramps intersection is shown in **Figure 5**.



1. Northbound Thru + Southbound Thru

2. Northbound Thru + Northbound Left

3. Westbound All

Northbound Left + LRT, when LRT present

Source: METRO, 2011.

Figure 5. At-Grade Scenario Phasing Diagram at 51st Avenue/I-10 WB Ramps

In practice, an LRT-only signal would indicate to LRT operators when they should leave the upstream station to arrive at the 51st Avenue intersection during Phase 2. With the assumption that such “starter signals” would be used, LRT arrivals at the intersection need not be considered random. The time estimate for a westbound train to clear the intersection starting from a stop at the station just east of the intersection was derived as follows:

Distance to clear:

- 3-car train is 279 feet long (93 feet per vehicle);
- The train stopped 200 feet east of 51st Avenue’s east curb line;
- 51st Avenue is 110 feet wide at the crossing.

For the tail of the train to clear the intersection, the train must travel 589 feet (the sum of the 3 distances above). Acceleration is considered uniform at low speeds; METRO design criteria indicate maximum LRT acceleration is 4.4 feet/second^2 (3.0 miles per hour per second), but an operating acceleration of 3.0 feet/second^2 is used for this analysis to account for passenger comfort. Using the equation for uniform acceleration, the time for a train starting from rest to clear the intersection would be just under 20 seconds. This crossing time is less than the total 24-second duration of Phase 2 at the intersection. Therefore, it is reasonable to assume for the sake of this analysis that the LRT crossing event could start and end within the time allotted for Phase 2, and that no other phase would need to be impacted by the LRT crossing event. This assumption might not hold at other at-grade crossing locations with different signal timing parameters.

An eastbound train could cross in less than 20 seconds because it would moving when the 'proceed' time begins (not starting from rest) and because it does not need to travel as far to clear the crossing. However, it is not realistic for an eastbound train to enter the crossing at the exact moment when Phase 2 begins. Some additional time would be needed to allow the train operator and the signal system to determine that (a) the intersection is clear, and (b) the proper "proceed" indication has been displayed on the LRT signal(s) present at the intersection. Even with the additional time that would be needed for these, it is assumed for the sake of a basic feasibility determination that crossing events involving either eastbound or westbound LRT trains could be accommodated within the 24-second duration of Phase 2.

The LRT operating condition simulated for this initial study assumes that trains are only permitted to cross 51st Avenue during Phase 2 as described previously, and not during other signal phases. It is important to note that it is also possible for trains to be accommodated during Phase 3, with a similar impact to overall operations. This case was not examined directly for this study.

The LRT crossing event is expected to occur 6 times per hour in each direction, for a total of 12 crossing events per hour. With the 90-second cycle in use in the study area, there are 40 cycles in an hour. As such, at most 30% of the time (12/40), phase 2 will be used by a crossing LRT train, and therefore will be closed to northbound through traffic at the Westbound Ramps intersection (other intersections would be unaffected). Northbound through traffic at this intersection also has the use of phase 1, and its duration (32 seconds) would remain constant regardless of LRT presence under the assumptions of this analysis. Phase 2 (24 seconds) represents 42.9% of the northbound through movement's available green time (24/56).

To reflect the 30% chance that the train crossing could replace phase 2 in the At-Grade scenario, Synchro's capacity (Saturation Flow Rate) for the phase 2 portion of the northbound through movement at that intersection was reduced by 30%. Because phase 2 represents 42.9% of the northbound through movement's available green time, the reduction in total northbound through capacity was 30% of 42.9%, or 12.9%. The capacity of the other movement that is allowed during phase 2, for northbound left turning vehicles, would be unaffected because they would be allowed to proceed during an LRT crossing event.

3.0 RESULTS

Results are presented for the Synchro analysis and then for the VISSIM analysis. These are followed by a discussion of the differences between the two, as well as the potential drivers of those differences.

3.1 Synchro Analysis

Synchro analysis was based on the simple reduction in average saturation flow rate of the northbound through traffic movements to reflect the at-grade LRT crossing activity associated with METRO's project.

Table 2. LRT Impact Analysis Results

PM Peak Hour Statistic	Grade-Separated	At-Grade
Phase Duration	24 seconds	24 seconds
Volume/Lanes	1500 vehicles[1]/3 Lanes	1500 vehicles[1]/3 Lanes
Movement Capacity	4,803 veh/hr. of green	4,183 veh/hr. of green
Movement LOS (Delay)	**A (2.5 sec/veh)**	**A (4.4 sec/veh)**

1. Includes portion of Northbound Through volume that is served in Phase 1

It indicated that in the 2035 p.m. peak hour at the 51st Avenue/Westbound Ramps intersection, the northbound through movement would operate at LOS A (2.5 seconds of delay per vehicle) in the Grade-Separated scenario and LOS A (4.4 seconds of delay per vehicle) in the At-Grade scenario. This difference, while it technically represented a large percentage, was insignificant in light of the fact that the projected

2035 PM peak hour LOS for the northbound through movement would remain A. The result made it clear that the portion (12.9%) of that movement's capacity at the intersection that would be replaced by an LRT crossing phase was not necessary for the successful overall operation under the conditions analyzed.

Given the complexity of the traffic operations on 51st Avenue in the vicinity of I-10 and the implications to overall interchange traffic operations of a LOS failure due to LRT crossing activity, the project steering committee requested a more in-depth analysis utilizing the VISSIM software.

3.2 VISSIM Analysis

Although four intersections were analyzed along 51st Avenue, substantial differences in peak hour intersection delay were only observed at the "I-10 Westbound Ramps" signal because the intersections operate at LOS D or better with no queue spillback, and that intersection is the only one of the four analyzed where changes in ramp geometry or signal timing were proposed as part of the LRT grade crossing improvements. **Table 2** summarizes the peak hour intersection delay results indicated by VISSIM modeling (average of ten runs with different random number seeds).

Table 2. 2035 Peak Hour LOS and Intersection Delay at 51st Avenue/I-10 Westbound (seconds/vehicle)

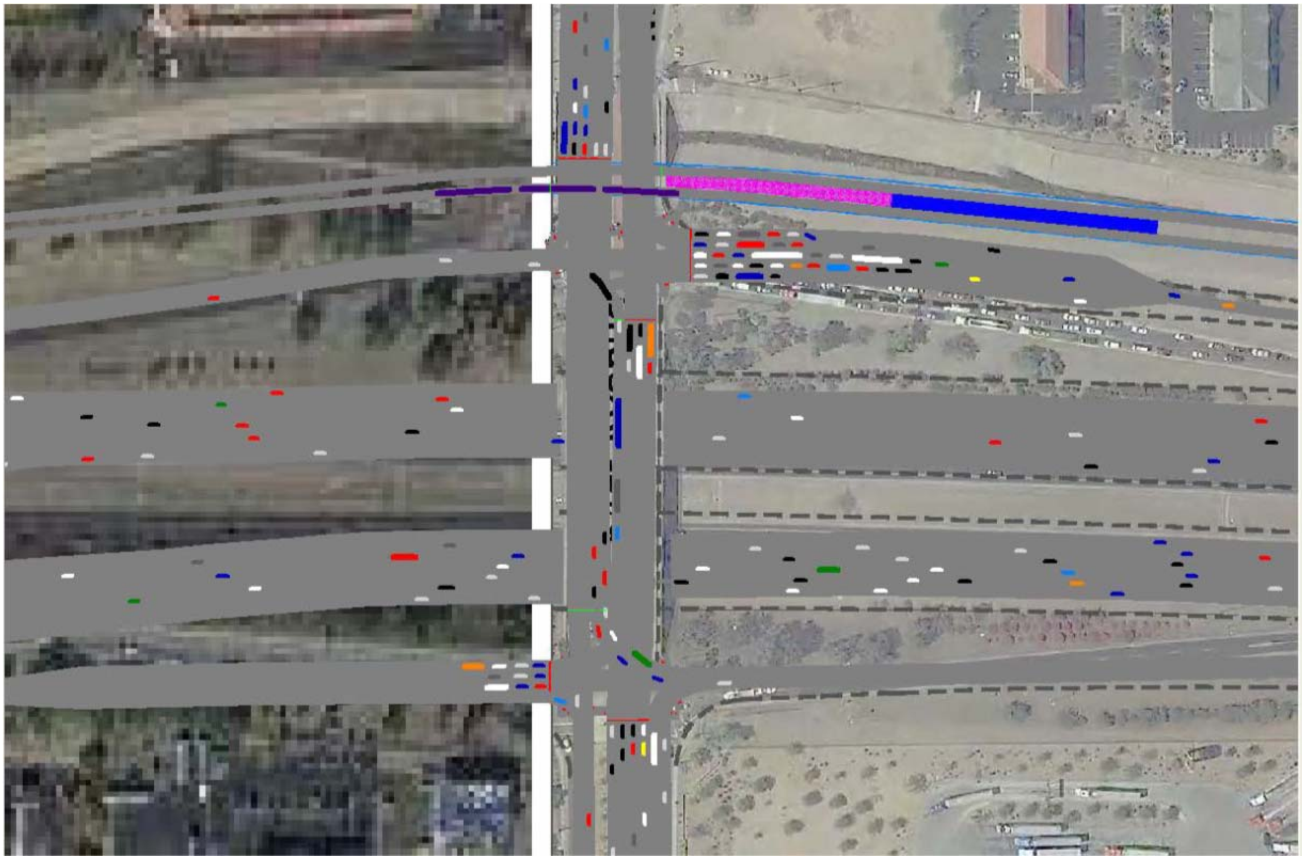
Peak Hour	Grade-Separated	At-Grade	Difference	%
AM Peak Hour	C (25.3)	D (35.9)	+ 10.6	42%
PM Peak Hour	C (24.1)	C (30.6)	+ 6.5	27%

The At-Grade scenario showed a fairly large difference in projected 2035 peak hour LOS at the I-10 Westbound Ramps signal in both peak hours, but in each case the resulting LOS was still well within reasonable delay/LOS limits. While the a.m. peak hour change of an additional 10.6 seconds of delay per vehicle represents an increase of about 42% in average delay, the resulting delay is just over the LOS C/D threshold of 35.0 seconds per vehicle. A good portion of of this difference appears to be attributable to the loss of right-turn-on-red at the intersection. The p.m. peak hour change at that same intersection is smaller in terms of both real value (6.5 seconds per vehicle) and percentage (27%), and the resulting LOS is C. The other intersections exhibited small changes in delay as a result of the LRT grade crossing. Qualitative assessments of the VISSIM on-screen animation are also possible, but difficult to replicate in paper form. A representative screen-capture image is presented here as **Figure 6**. North is toward the top of this image.

3.3 Comparison of Synchro and VISSIM Results

The Synchro results indicated that the LOS of the northbound through movement would be very good (A) and would remain unchanged as a result of the grade-separation project. The VISSIM simulation indicated that when looking at the interchange area on a more comprehensive basis, the At-Grade scenario would result in a satisfactory 2035 peak hour LOS for the overall intersection as well. The VISSIM results indicated a LOS result closer to capacity. Several key differences between the Synchro and VISSIM analyses contributed to differences in the results. Specifically, the VISSIM analysis included the following elements the Synchro analysis did not:

- 2035 traffic volume estimates
- A.M. Peak Hour analysis
- Overall intersection LOS focus
- Inclusion of adjacent intersections
- Microsimulation approach
- Modeling of pedestrian crossings (and their impacts to vehicle delay) based on LRT station activity
- Additional truck traffic volumes related to a large existing truck stop in the southeast quadrant of the interchange



Source: METRO, 2011.

Figure 6. Build Condition VISSIM Screen Capture Image

This image from the p.m. peak hour simulation shows an eastbound 3-car train crossing 51st Avenue, with the northbound left turn allowed. The LRT station platform is shown in blue in the upper right.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The simulation analysis documented in this report indicates that the proposed at-grade LRT crossing of 51st Avenue just north of I-10 would operate within acceptable limits of delay and would not be expected to cause queuing problems in the 2035 peak hours. The finding that the addition of LRT crossing activity to the 51st Avenue interchange would not result in substantial delay is consistent with both the visual output of the simulation model and the earlier planning-level results estimated using Synchro.

This finding for 51st Avenue can reasonably be extended to the other three crossings at the planning level because 51st Avenue was selected as a "worst-case" location for this initial study. The technical committee agreed that a detailed analysis of the other three intersections was not necessary. Even though the traffic study indicated that traffic operations at 51st Avenue might not be adversely affected in 2035, the technical committee took factors other than traffic analysis results into consideration in recommending grade-separation of the 51st Avenue crossing. The technical committee further agreed that the lower projected traffic volumes and other key factors at the other three major crossing locations considered do not appear to warrant recommending a grade separation at this time.

The coordination and collaboration of the technical committee was a very important factor in the success of this project. It led to a well-supported planning-level decision to avoid costly and unnecessary grade-separation and showed that while LRT and diamond interchanges may not be best friends, they can work together.